Hyperspectral and Multispectral Atmospheric Correction Algorithms for Supporting the NASA PACE Mission

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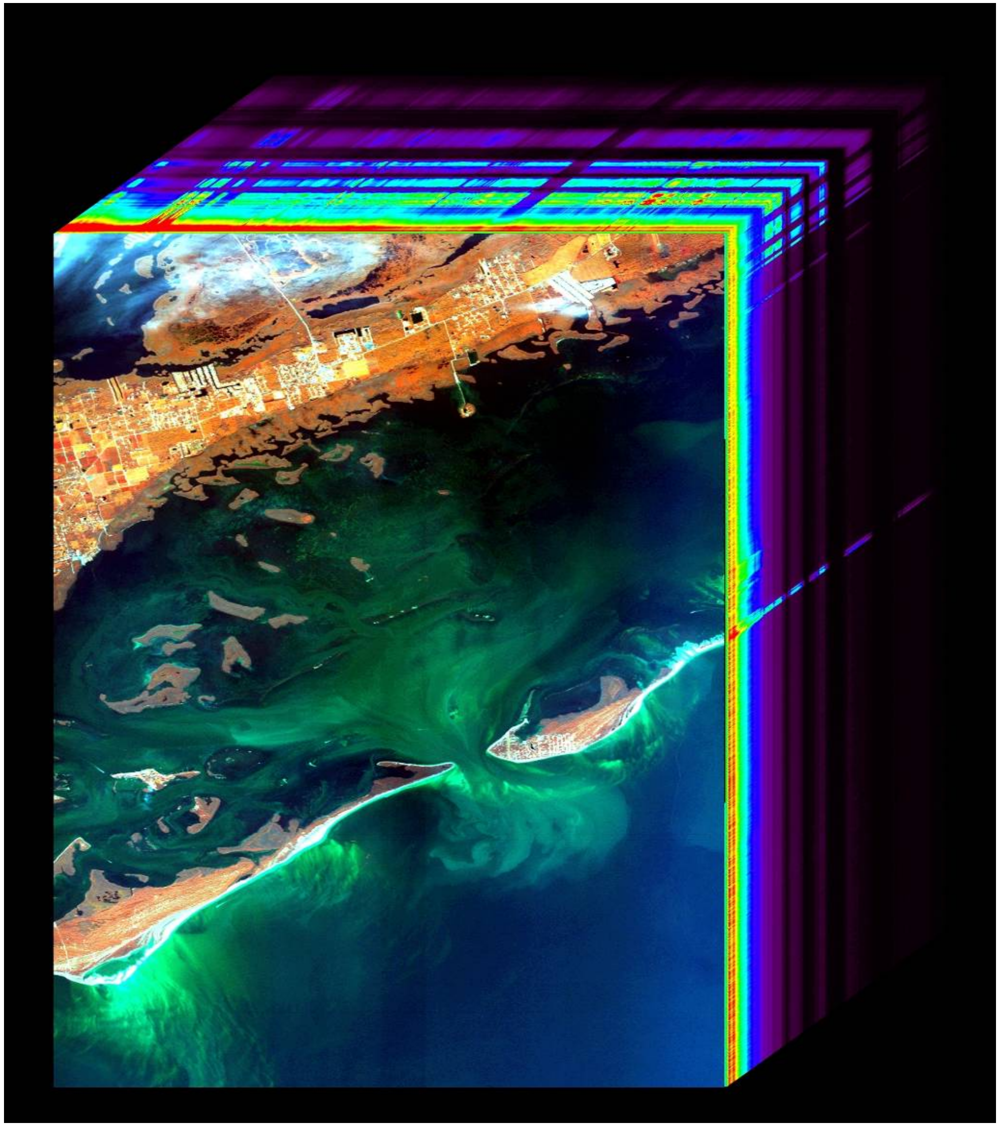
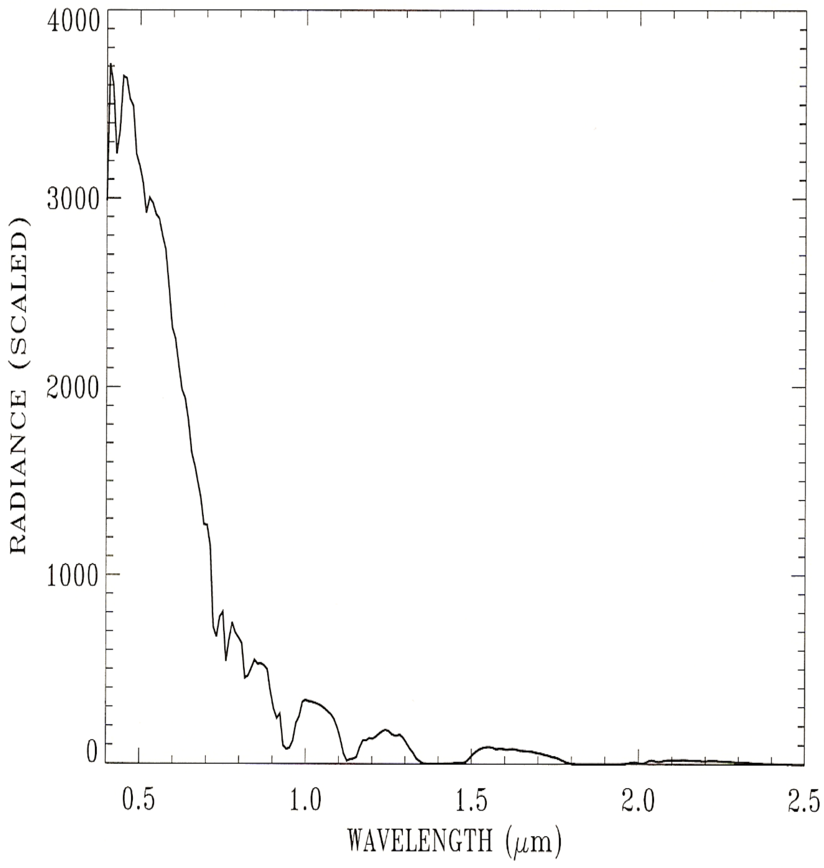
Imaging Spectrometry Concept



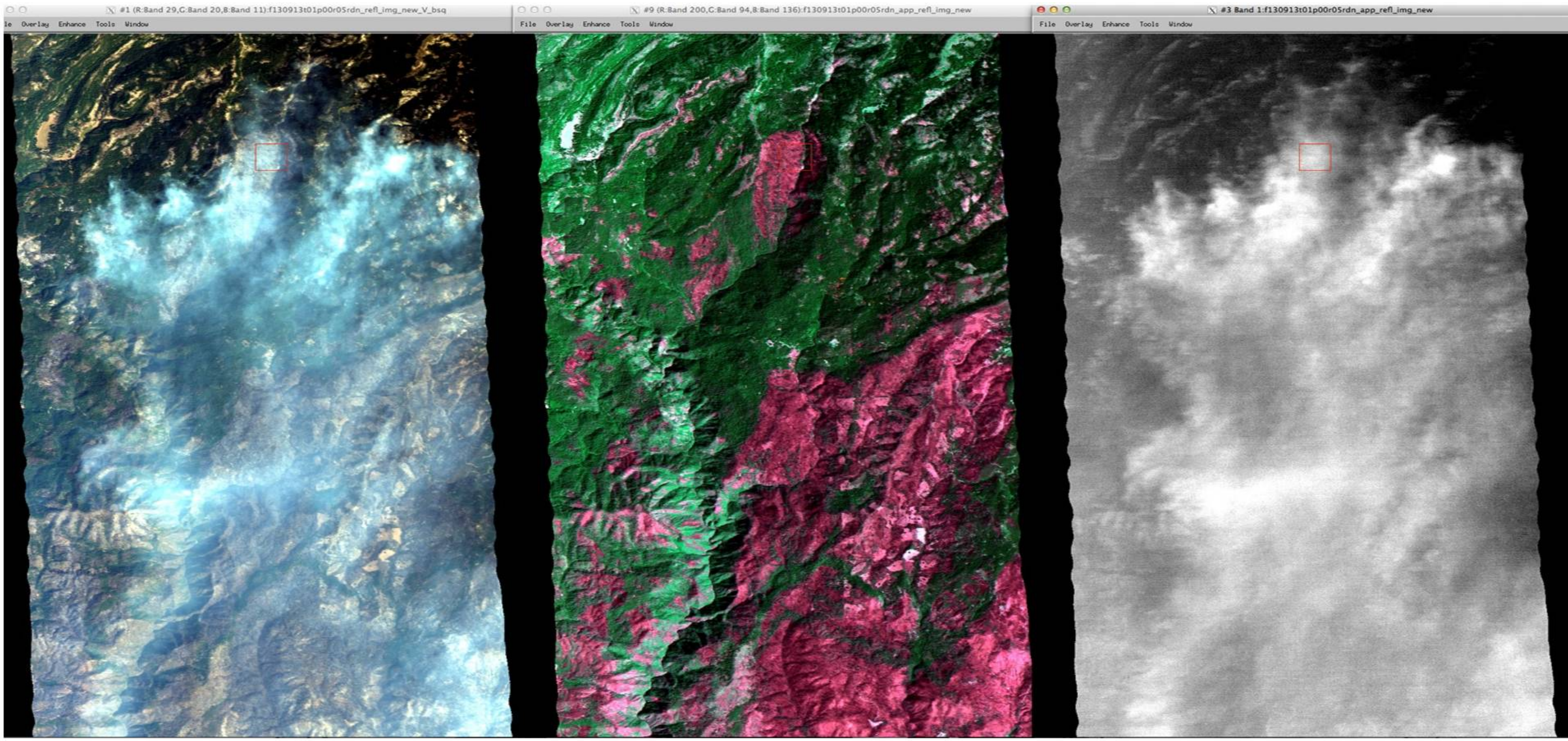
A Sample Spectrum



Radiances above one μm are very small.

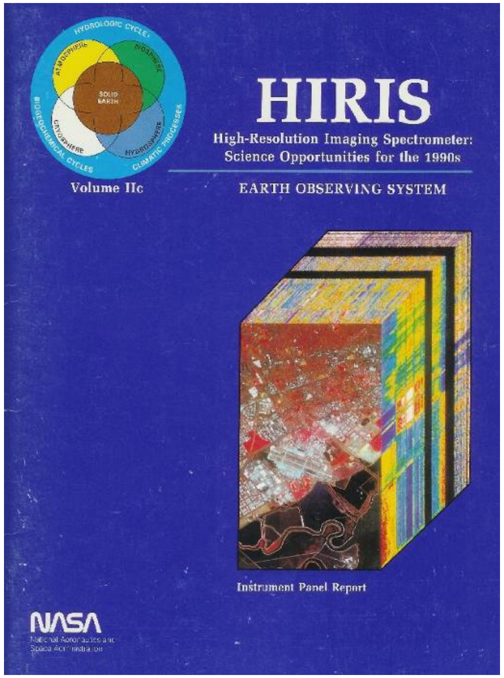
Aerosol Scattering Effects
(Illustrated with AVIRIS RIM Fire Data)

True Color Image (R: 0.64, G: 0.55, B: 0.46 μm) | False Color Image (R: 2.13, G:1.24, B:1.64 μm) | B/W Single Channel Image (0.37 μm)



Smoke is seen in visible channel images, but disappears in the SWIR channel images. Smoke particle size is typically 0.1 – 0.2 μm. The UV channel at 0.37 μm is especially sensitive for smoke detection.

Brief History on ATREM Algorithm Development



In the late 1980s, MODIS & HIRIS were envisioned to be parts of the massive NASA EOS Program. Professor Alex. Geotz at University of Colorado in Boulder, Colorado was the NASA-selected HIRIS Team leader. He envisioned the need of a model-based atmospheric correction algorithm around 1987.

I worked with Dr. Goetz at U. of Colorado from 1988 to 1992 for the HIRIS Project to develop the 1st band-model-based hyperspectral atmospheric correction algorithm - ATREM. The ATREM source code was publicly released through U. of Colorado to more than 300 researchers worldwide in mid-1990s.

- Timeline of algorithm development:
- ATREM – 1st land version (~1991, band model) to support the AVIRIS/HIRIS Project. A Paper was published in 1993 on RSE.
- ATREM - upgraded land version (~1997, line-by-line model) to support the Navy COIS/NEMO Project. Reported in a 1997 SPIE extended abstract.
- ATREM – 1st ocean version (~1999, line-by-line, spectrum matching using ***channels above 0.86 µm for Case 2 waters***, based on R. Fraser's formulation and multi-layer atmospheric model). A paper was published in 2000 on Applied Optics.

Selected Publications On Atmospheric Corrections and on the Analysis of AVIRIS & MODIS Data

- **1993** - Gao, B.-C., K. H. Heidebrecht, and A. F. H. Goetz, Derivation of scaled surface reflectances from AVIRIS data, *RSE., 44*, 165-178. (Cited by **396** journal articles – till December 22, 2014).
- **2000** - Gao, B.-C., et al., Atmospheric correction algorithm for hyperspectral remote sensing of ocean color from space, Appl. Opt., 39, 887-896. (Cited by **178).**
- **2007 -** Gao, B.-C., M. J. Montes, R.-R. Li, H. M. Dierssen, and C. O. Davis, An atmospheric correction algorithm for remote sensing of bright coastal waters using MODIS land and ocean channels in the solar spectral region, TGRS, 45, 1835-1843. (Cited by **36**).
- **2009** - Atmospheric correction algorithms for hyperspectral remote sensing data of land and ocean, RSE, 113, S17-S24. (Cited by 21, **119**).
- **2003** - Li, R.-R., Y. J. Kaufman, B.-C. Gao, and C. O. Davis, Remote sensing of suspended sediments and shallow coastal waters, TGRS, 41, 559-566, 2003. (Cited by **110**)
- **1990** - Gao, B.-C., and A. F. H. Goetz, Column atmospheric water vapor and vegetation liquid water retrievals from airborne imaging spectrometer data, *JGR., 95*, 3549-3564. (Cited by **408**).
- **1993** - Gao, B.-C., A. F. H. Goetz, and W. J. Wiscombe, Cirrus cloud detection from airborne imaging spectrometer data using the 1.38 µm water vapor band, *GRL, 20*, 301-304. (Cited by **156**).
- **1996** - Gao, B.-C., NDWI - A normalized difference water index for remote sensing of vegetation liquid water from space, *RSE, 58*, 257-266. (Cited by **1364**).

Adopting R. Fraser Formulation

$$L_t = L_0(\lambda; \theta, \phi; \theta_0, \phi_0; z_{sen}, z_{sfc}; \tau_a) +$$
$$L_{sfc}(\lambda; \theta, \phi; \theta_0, \phi_0; z_{sen}, z_{sfc}; \tau_a; W)\, t(\lambda; \theta; z_{sen}, z_{sfc}; \tau_a) +$$
$$L_w(\lambda; \theta, \phi; \theta_0, \phi_0; W; C)\, t'(\lambda; \theta; z_{sen}, z_{sfc}; \tau_a)$$

L_t	=	measured radiance
L_0	=	path radiance (i.e., atmospheric scattering)
L_{sfc}	=	direct and diffuse radiance reflected off ocean surface
L_w	=	water (or ground) leaving radiance
t	=	diffuse + direct upward transmission
t'	=	diffuse upward transmission
τ_a	=	aerosol optical properties
W	=	wind speed
C	=	water column and bottom constituents
θ, ϕ	=	view zenith and azimuth angles
θ_0, ϕ_0	=	solar zenith and azimuth angles
z_{sen} , z_{sfc}	=	sensor and surface altitudes

Relevant Equations and Definitions

In the absence of gas absorption, the radiance at the satellite level is:

$$L_{obs} = L_0 + L_{sfc}\, t'_u + L_w\, t_u, \qquad (1)$$

L_0: path radiance; L_w: water leaving radiance;

L_{sfc}: radiance reflected at water surface; t_u: *upward transmittance*

Define $$L_{atm+sfc} = L_0 + L_{sfc}\, t'_u \qquad (2)$$

Eq. (1) becomes: $$L_{obs} = L_{atm+sfc} + L_w\, t_u \qquad (3)$$

Multiply Eq. (3) by π and divide by $(\mu_0\, E_0)$, Eq. (3) becomes:

$$\pi\, L_{obs} / (\mu_0\, E_0) = \pi\, L_{atm+sfc} / (\mu_0\, E_0) + \pi\, L_w\, t_d\, t_u / (\mu_0\, E_0\, t_d) \qquad (4)$$

Several reflectances are defined as:

Satellite apparent reflectance: $$\rho^*_{obs} = \pi\, L_{obs} / (\mu_0\, E_0), \qquad (5)$$

$$\rho^*_{atm+sfc} = \pi\, L_{atm+sfc} / (\mu_0\, E_0), \qquad (6)$$

Water leaving reflectance: $$\boldsymbol{\rho_w = \pi\, L_w / (\mu_0\, E_0\, t_d) = \pi\, L_w / E_d} \qquad (7)$$

Remote sensing reflectance: $$\boldsymbol{R_{rs} = \rho_w / \pi = L_w / E_d} \qquad (7')$$

Substitute Eqs (5) – (7) into Eq. (4): $$\rho^*_{obs} = \rho^*_{atm+sfc} + \rho_w\, t_d\, t_u \qquad (8)$$

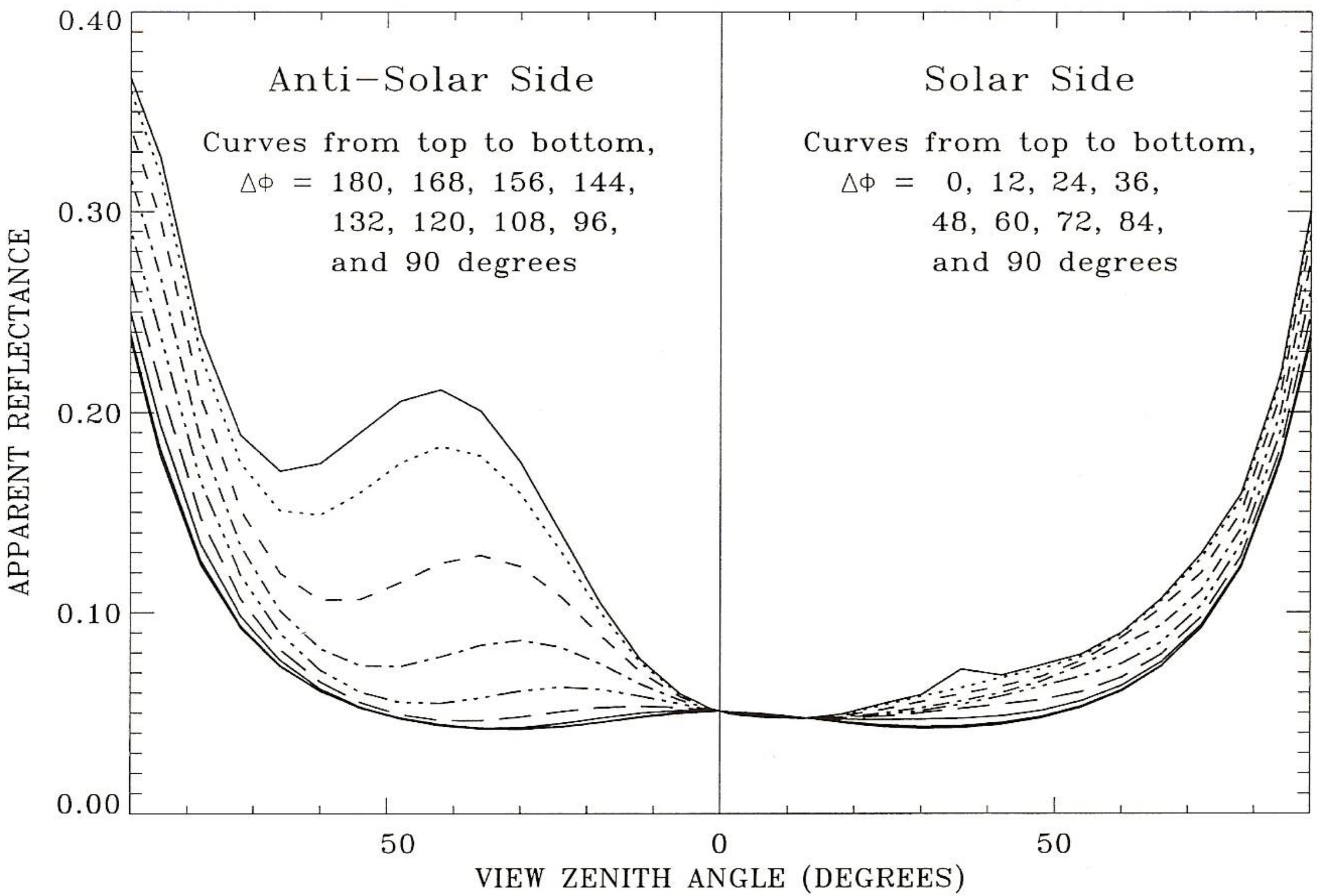
After consideration of gas absorption and multiple reflection between the atmosphere and surface and with further manipulation, we can get:

$$\rho_w = (\rho^*_{obs}/T_g - \rho^*_{atm+sfc}) / [t_d\, t_u + s\, (\rho^*_{obs}/T_g - \rho^*_{atm+sfc})\,] \qquad (11)$$

Gao, B.-C., M. J. Montes, Z. Ahmad, and C. O. Davis, Atmospheric correction algorithm for hyperspectral remote sensing of ocean color from space, Appl. Opt., 39, 887-896, February 2000.

Simulation of Sunglint Effects

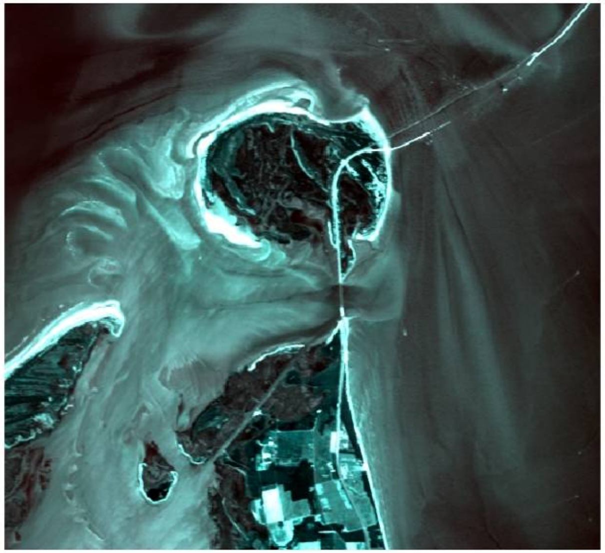
Using Ahmad and Fraser RT code to generate lookup tables



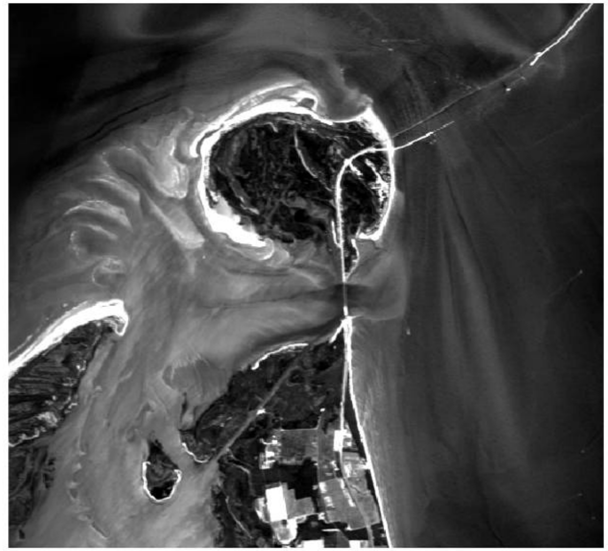
Wavelength: 0.61 micron

Coastal Waters Are Dark Above 0.86 Micron (AVIRIS Norfork Images)

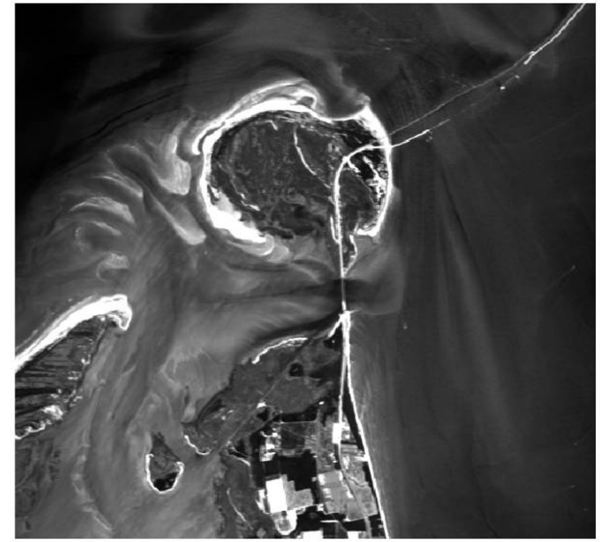
RGB (0.66, 0.55, 0.47 μm)



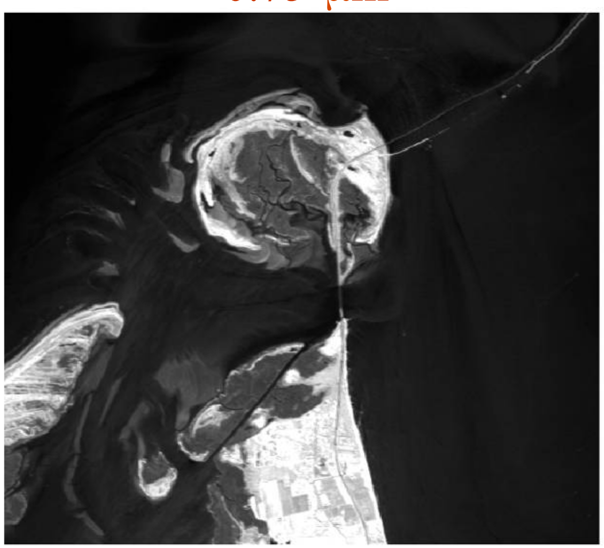
0.55-μm



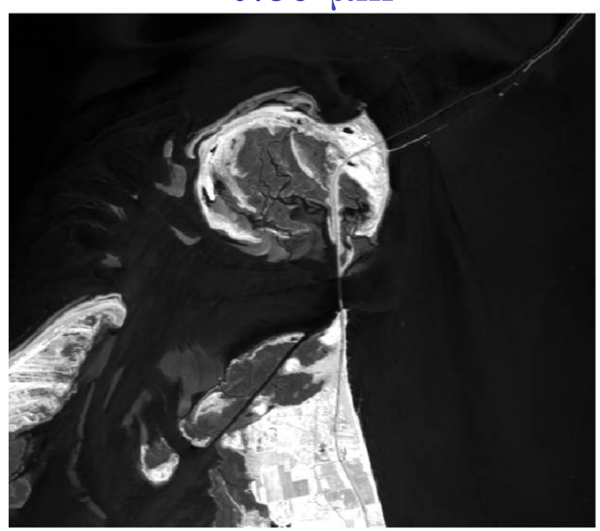
0.66-μm



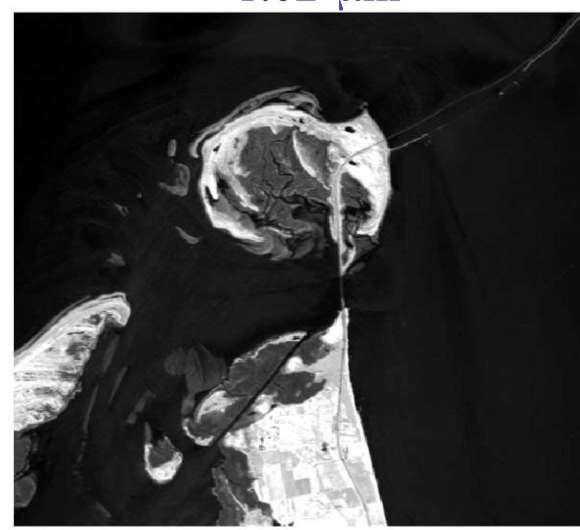
0.75-μm



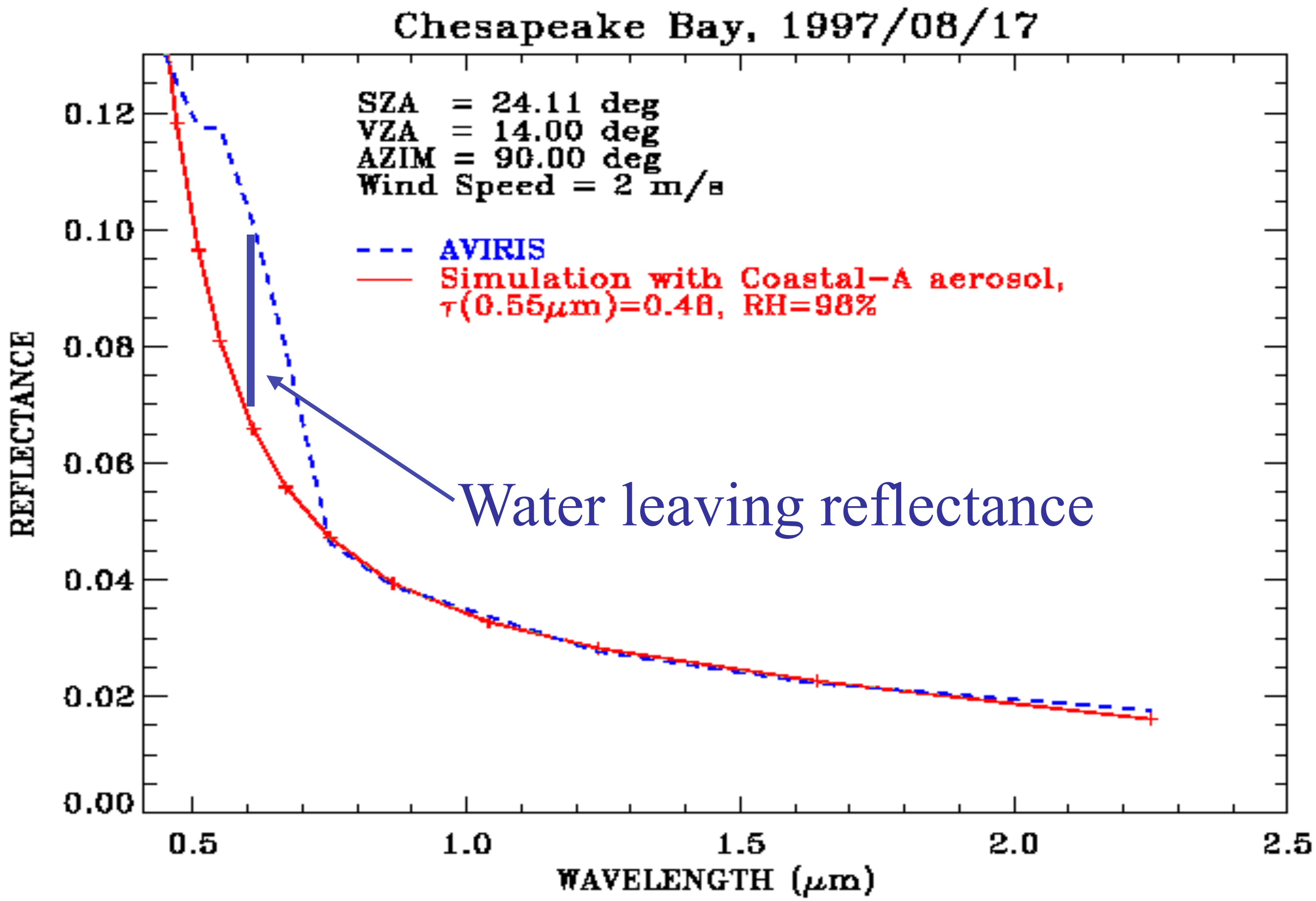
0.86-μm



1.02-μm

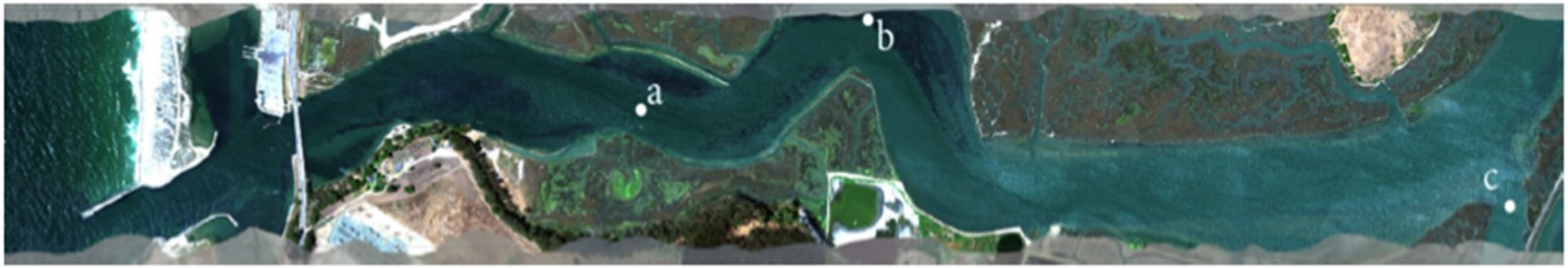


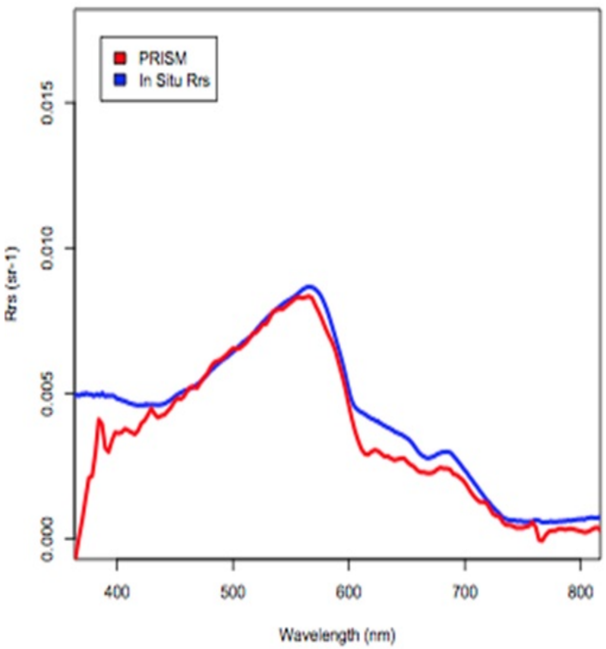
Atmospheric Correction for Water Surfaces



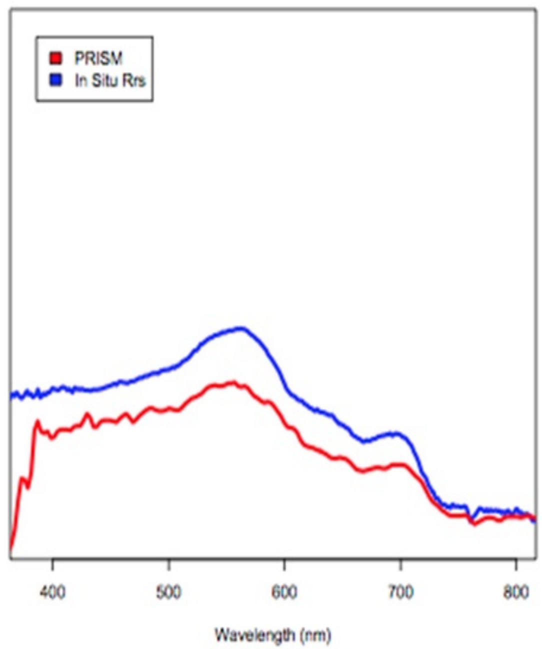
Channels at 0.86 and longer wavelengths are used to estimate atmospheric effects, and then extrapolate to the visible region. The differences between the two curves above are proportional to water leaving reflectances.

Sample Retrieval Results From PRISM Data & Comparison with Ground Measurements

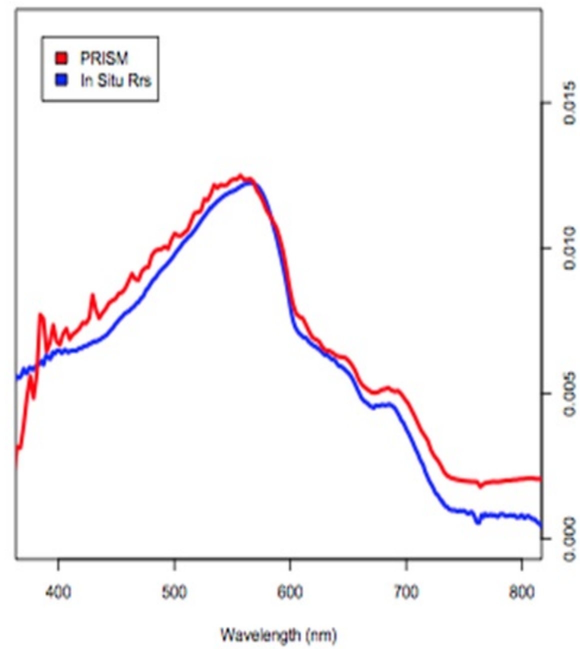




(a) West LOBO Buoy

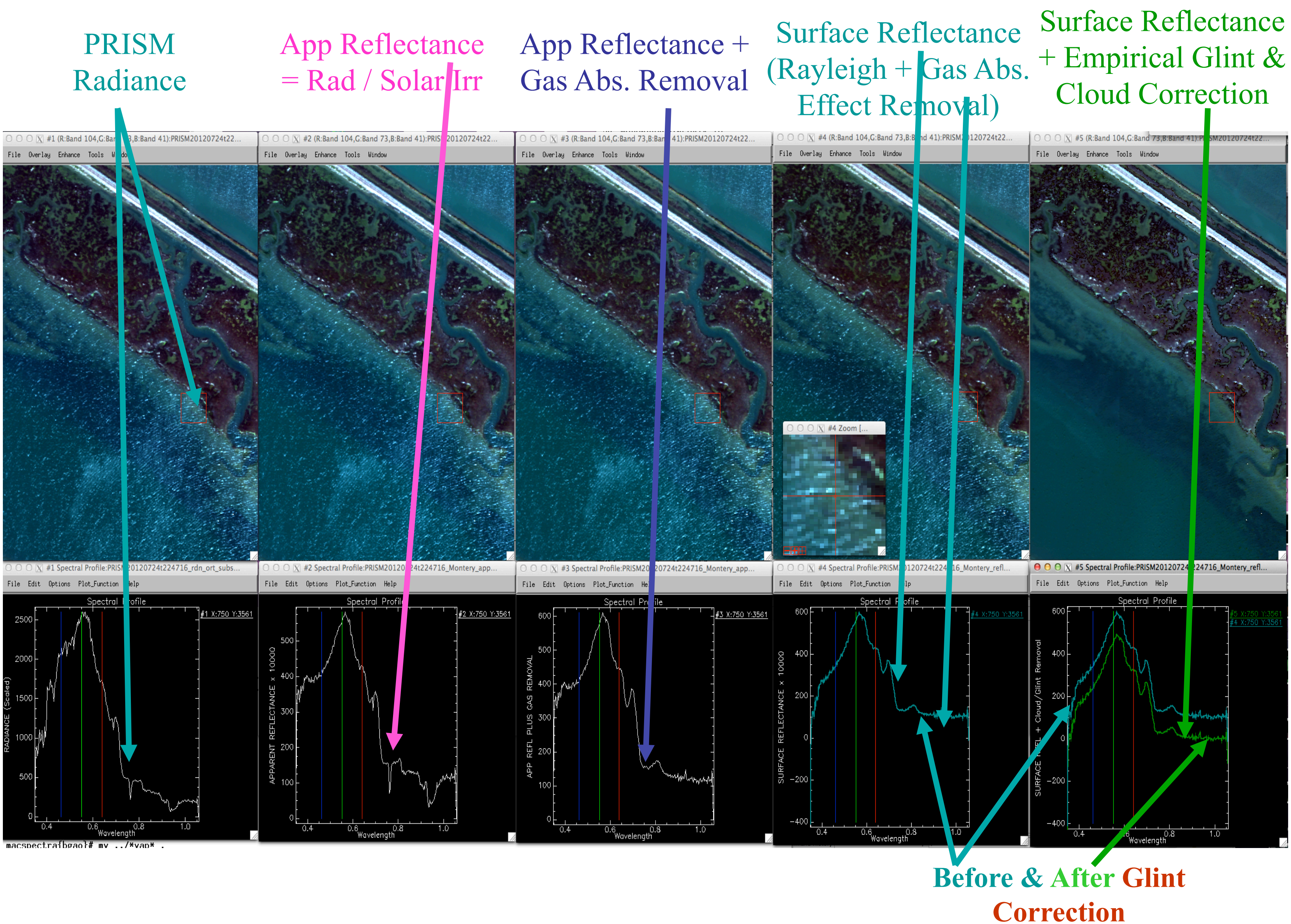


(b) Seal Bend Dense Eelgrass



(c) East LOBO Buoy

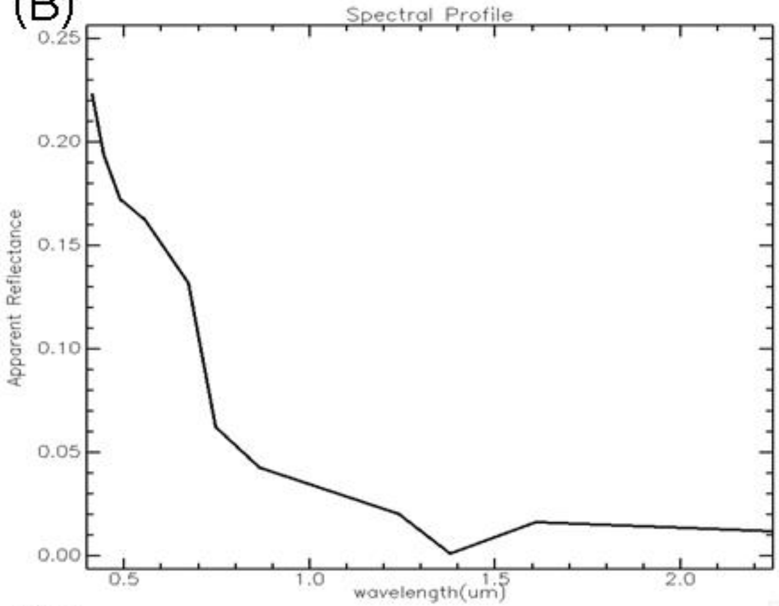
Sample Retrieval Results With Intermediate Data Products Illustrated



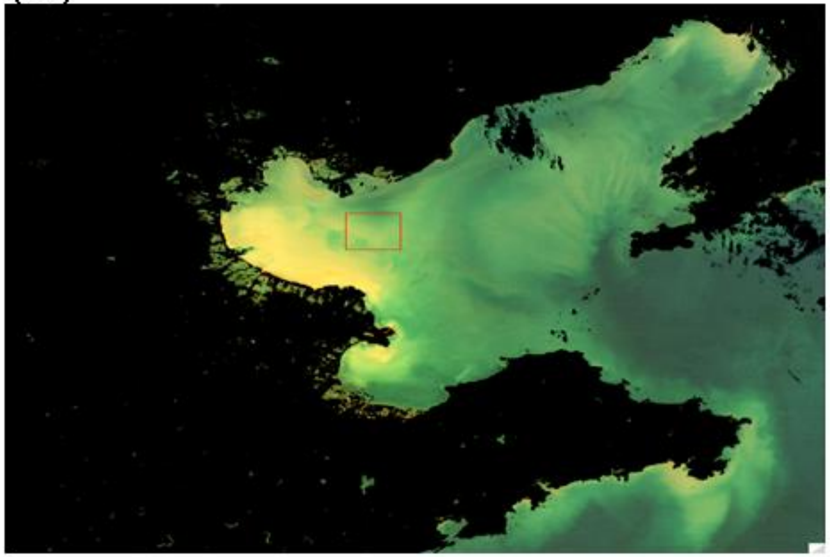
Sample VIIRS Ocean Color Results

(A)

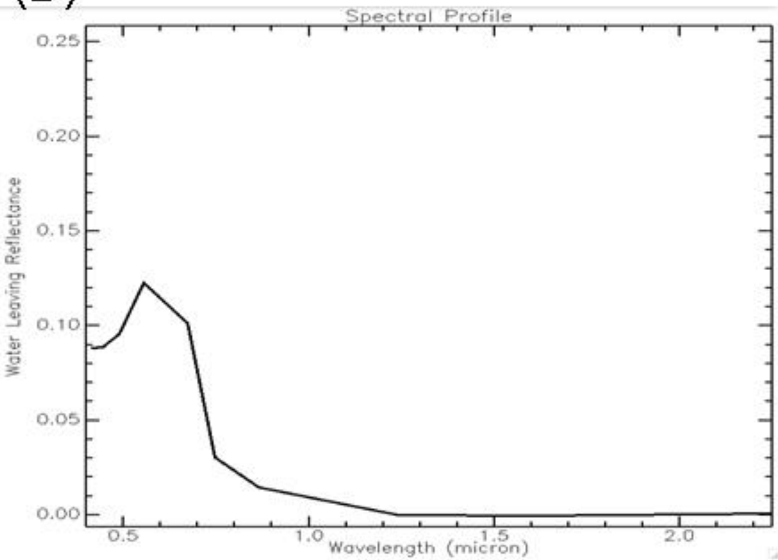
(B)



(C)



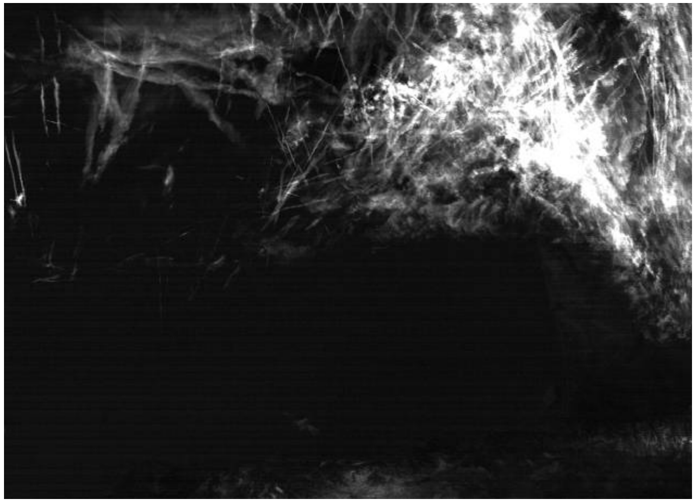
(D)



An Example of Cirrus Detection & Correction Using MODIS Data

MODIS Original RGB Image

1.38-µm MODIS Image



Cirrus-Corrected Image

SUMMARY

- We have developed hyperspectral and multi-spectral atmospheric correction algorithms for remote sensing of ocean color. Huge lookup tables generated with a vector radiative transfer code developed by Ahmad and Fraser (1982) and a spectral matching technique are used in these algorithms. Our hyperspectral algorithms have been used for operational processing large volumes of AVIRIS, PRISM, and HICO imaging spectrometer data. A land version algorithm has been used by researchers at NASA GSFC for processing EO-1 Hyperion data.

- Upgrades to our previously developed atmospheric correction algorithms are needed now, particularly in view of major advances in aerosol models. Specific upgrades include

  - Incorporation of absorbing aerosol models
  - Progress has been made in generating a new set of lookup tables, including absorbing aerosol models, for channels between 350 nm and 2500 nm, with the help from Dr. Pengwang Zhai at UMBC with his vector version of successive order of scattering radiative transfer code.
  - Progress has also been made in our retrieving algorithms to include channels (either UV or SWIR channels) with non-zero surface reflectance values for deriving aerosol parameters.